

# Recent results on RO climate data analysis

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# Overview

- UTLS studies [updates from Apr 2013 meeting]
  - I. Tropical width trends
  - II. Evaluation of CMIP5 geopotential height
- Uncertainty analysis beyond UTLS
  - III. Progress on stratospheric retrieval

# I. Width of tropical belt

*C. O. Ao and A. J. Hajj, Monitoring the width of the tropical belt with GPS radio occultation measurements, GRL, 2013.*

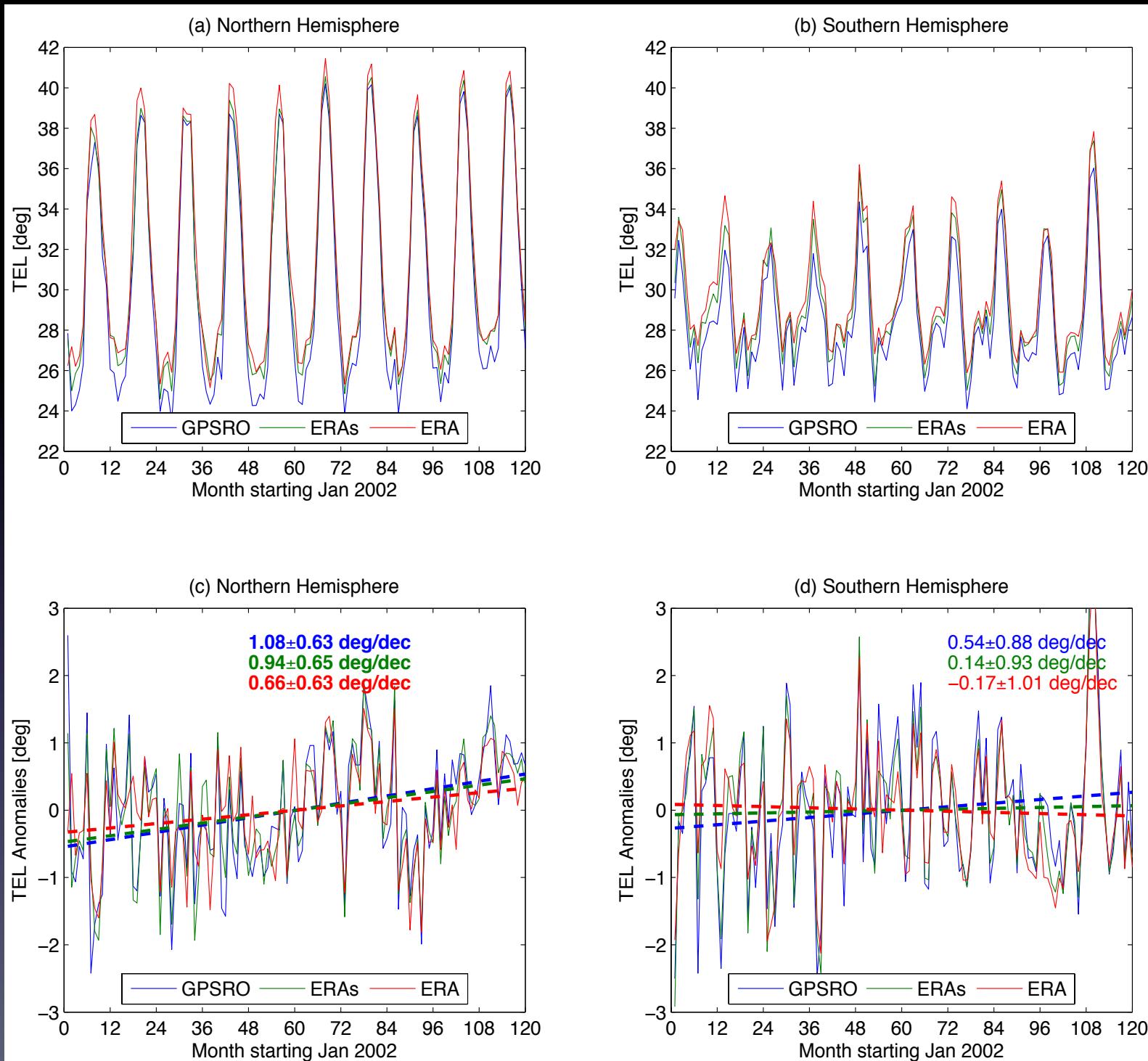
- Use a decade of RO data from CHAMP and COSMIC to infer the trend of the tropical belt width as defined by characteristics of the lapse-rate tropopause heights (ZLRT).
- Compare with ECMWF Reanalysis interim
  - “ERA”: full gridded 6 hourly profiles
  - “ERAs”: ERA interim subsampled at RO locations and times.

# Defining the width of tropical belt

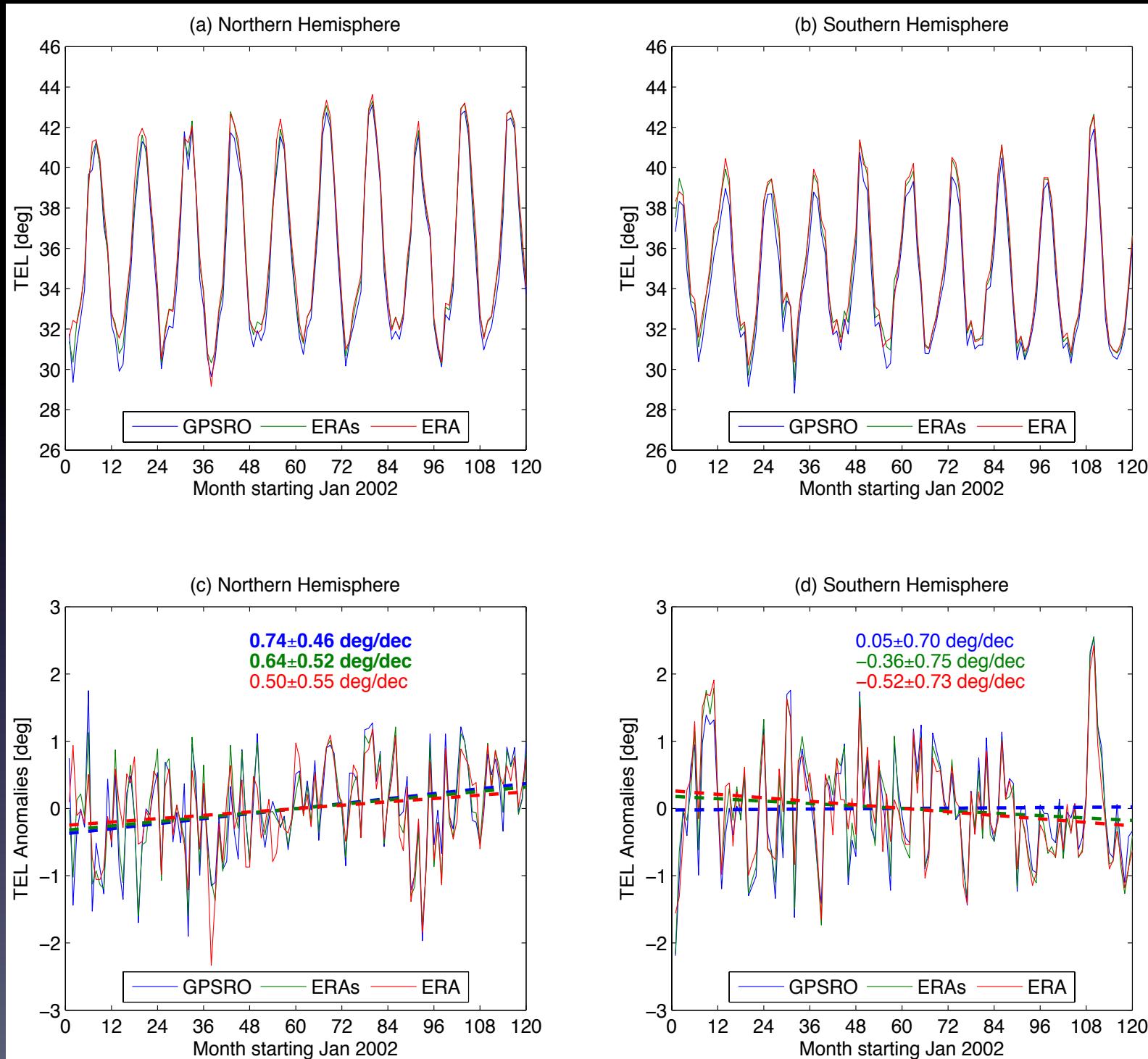
- Employed two definitions from Davis and Rosenlof (2012) for the tropical edge latitude (TEL) in each hemisphere:
  1. “Subjective criterion”: TEL is defined as the lat where ZLRT drops to 1.5 km below the tropical average (15S-15N).
  2. “Objective criterion”: TEL is the mean latitude weighted by the meridional gradient of ZLRT.

$$\phi_{TEL} = \left[ \sum_{\phi=15^\circ}^{60^\circ} \phi \frac{\partial Z_{LRT}}{\partial \phi} \cos \phi \right] / \left[ \sum_{\phi=15^\circ}^{60^\circ} \frac{\partial Z_{LRT}}{\partial \phi} \cos \phi \right]$$

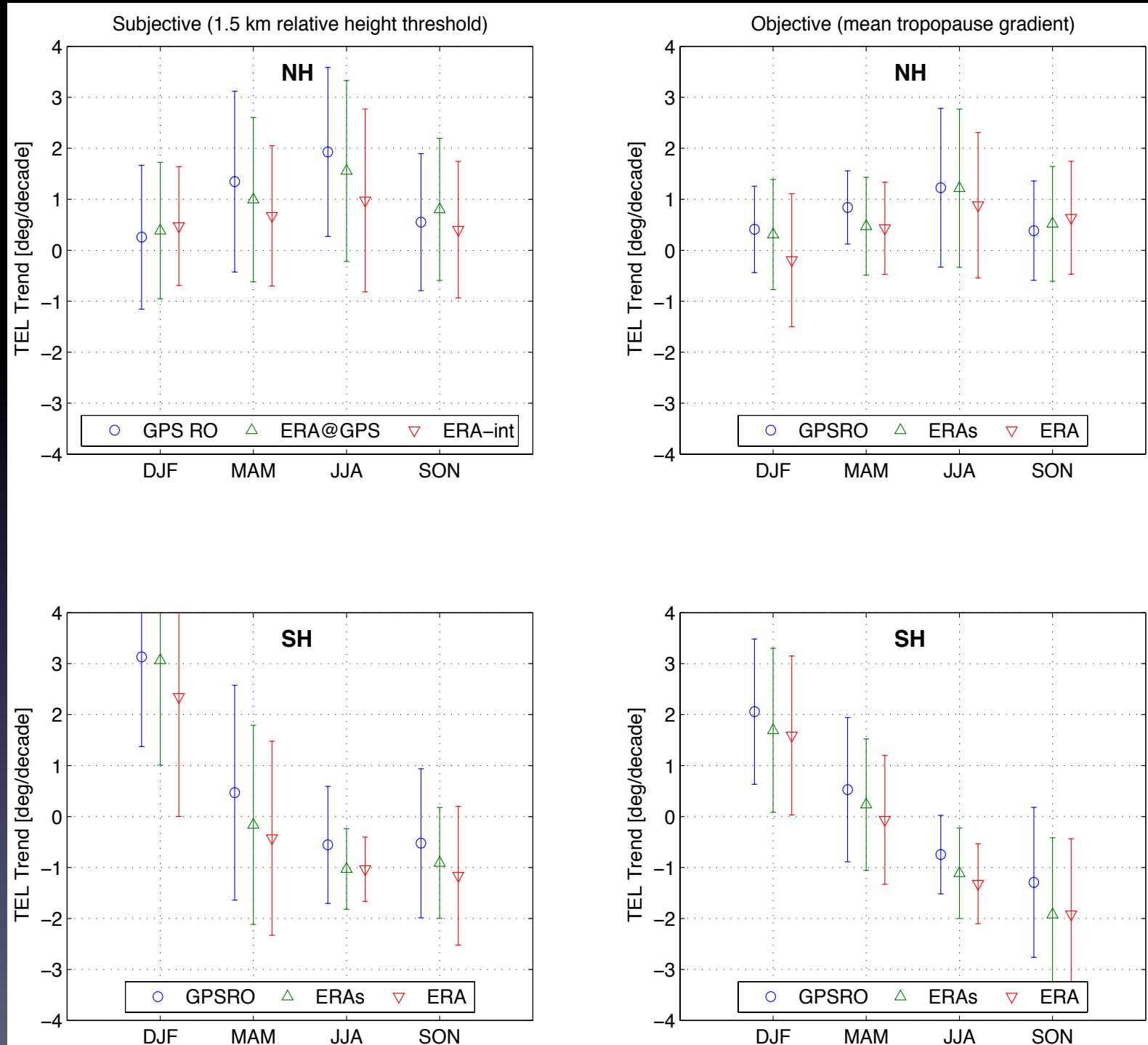
# Subjective Criterion



# Objective Criterion



## Seasonal Trends



# Conclusions (Part I)

- Statistically significant expansion of the tropical width was found in the NH ( $\sim 0.5$  deg over the last decade) but not in SH.
- RO and ERA-int are in good agreement but significant differences can be found in SH.
- Results suggest that NH and SH exhibit distinctly different seasonal trends. NH is expanding in all seasons, while SH expansion in summer (DJF) is countered by contraction in spring (SON).

## II. Evaluation of CMIP5 GPH

*C. O. Ao, J. Jiang, A. J. Mannucci, H. Su, O. Verkhoglyadova, C. Zhai, J. Cole, L. Donner, J.-L. Dufresne, T. Inversen, C. Morcrette, L. Rotstayn, M. Watanabe, and S. Yukimoto, Evaluation of CMIP5 upper troposphere geopotential height with GPS radio occultation observations, to be submitted to JGR.*

- Optimal fingerprinting studies based on simulated [Leroy et al. 2006] and observed [Lackner et al., 2011] RO data show that GPH in the UTLS is a sensitive indicator of climate change.
- We performed a detailed comparison of UTLS GPH between RO and CMIP5 models.
- We focus on the annual mean, seasonal cycle, and interannual variability of 200 mb GPH (proxy for the layer-averaged temperature of the tropospheric column.)

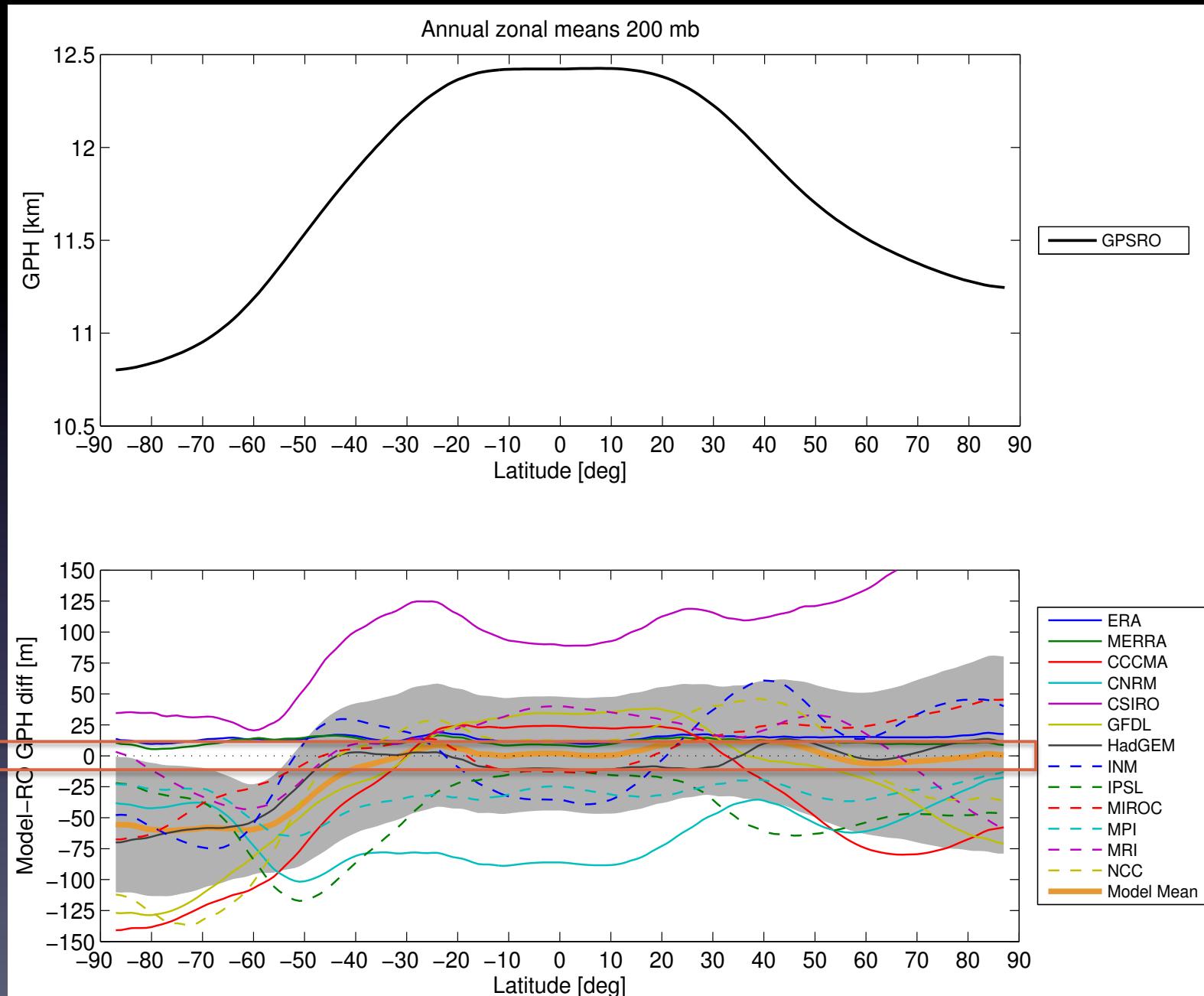
# Data

- GPS RO:
  - CHAMP (Jan 2002 – May 2006) ~ 150 profiles/day
  - COSMIC (June 2006 – Present) ~ 1500 profiles/day
  - Monthly gridded averages obtained via Bayesian mapping [Leroy et al. 2012]
- 11 CMIP5 Models (AMIP, mostly up to 2008):

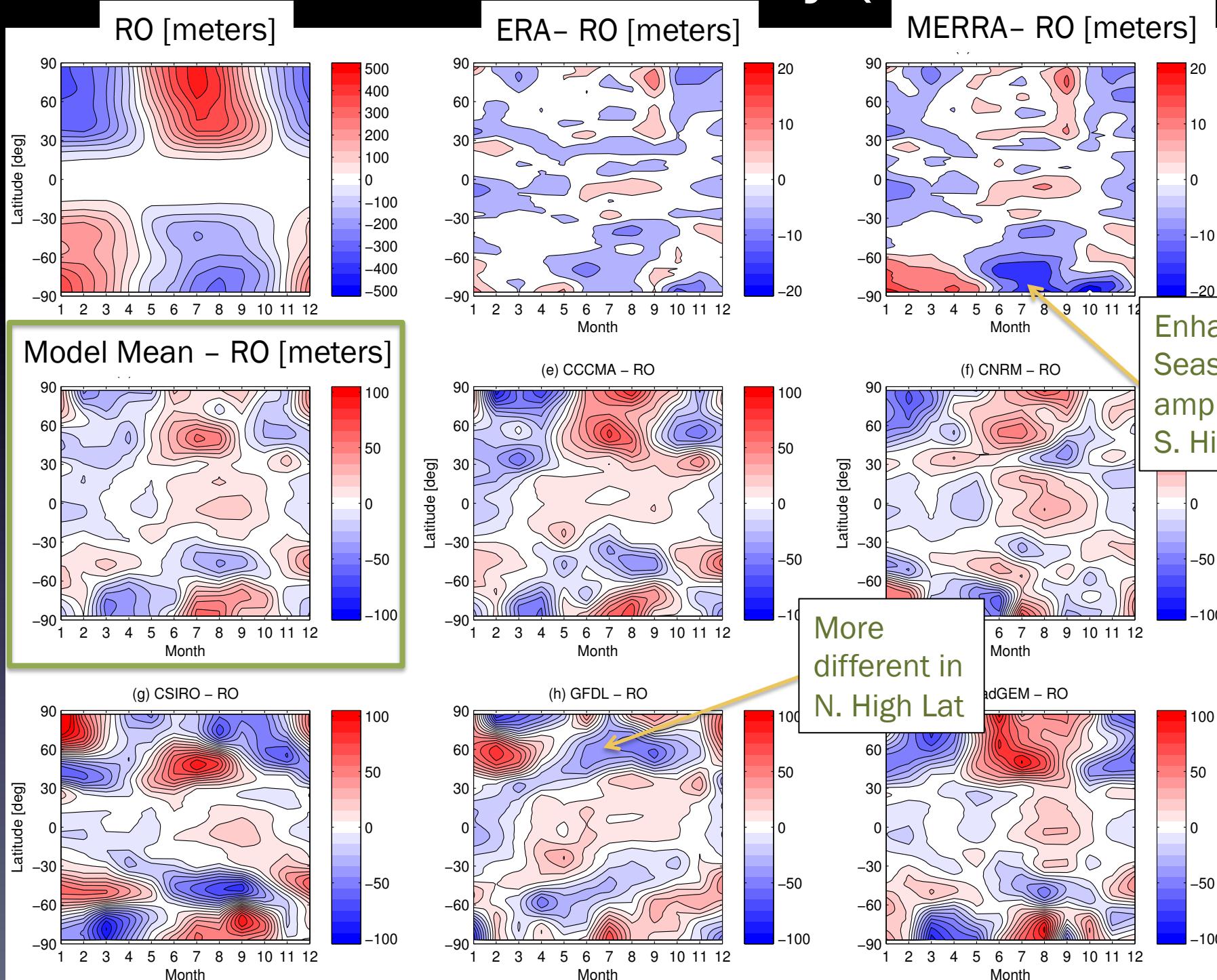
CCCMA AM4	CNRM CM5	CSIRO mk3.6	GFDL AM3
UKMO HadGEM2-A	INM CM4	IPSL CM5A-LR	MIROC5
MPI ESM-LR	MRI CGCM3	NCC NORESM1	

- Overlapping period: **2002–2008**.
- Reanalyses: **ERA interim & MERRA**, which did & didn't assimilate RO, respectively.

# Annual Mean (Zonal)



# Seasonal Variability (Zonal)

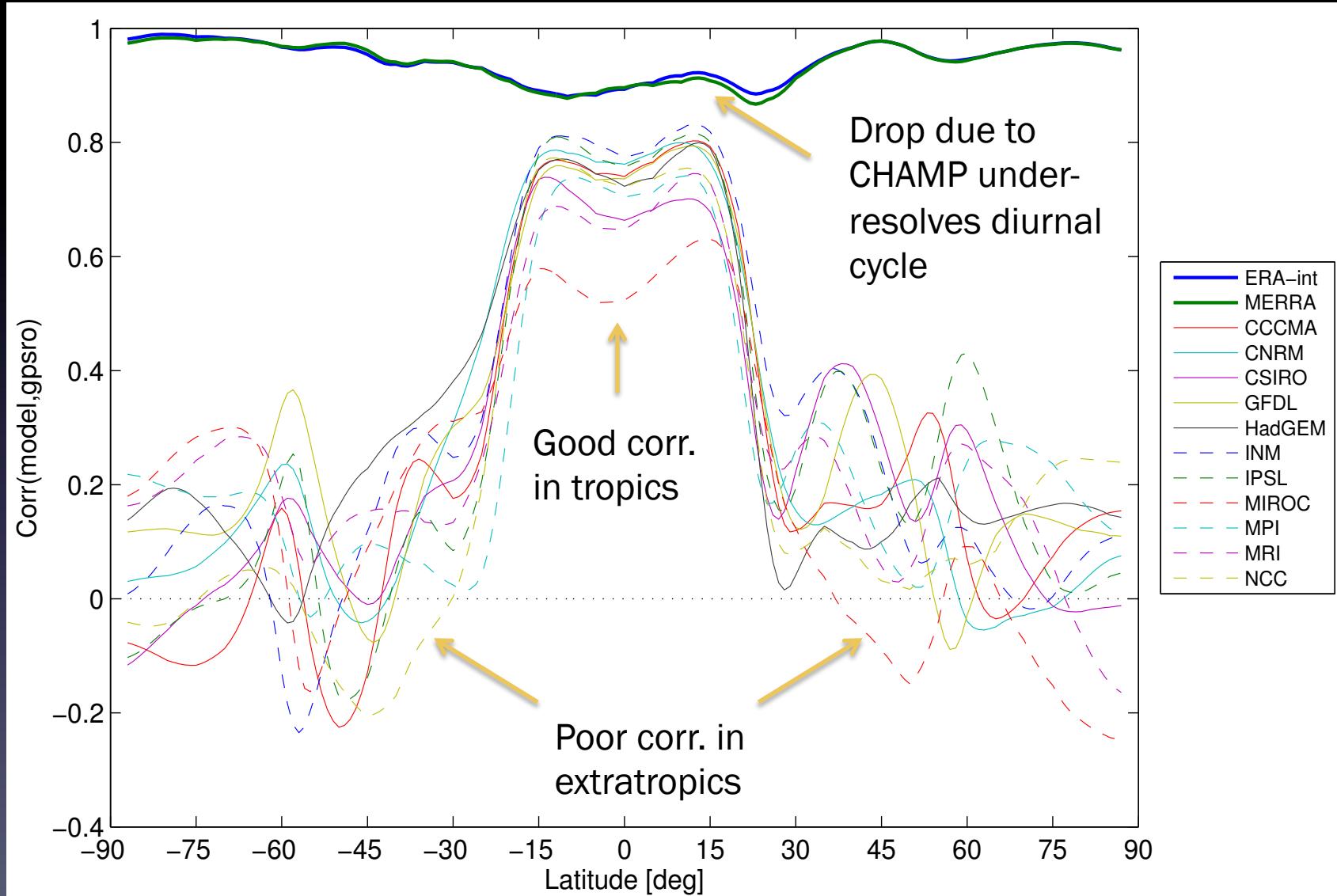


# Enhanced Seasonal amplitude in S. High Lat

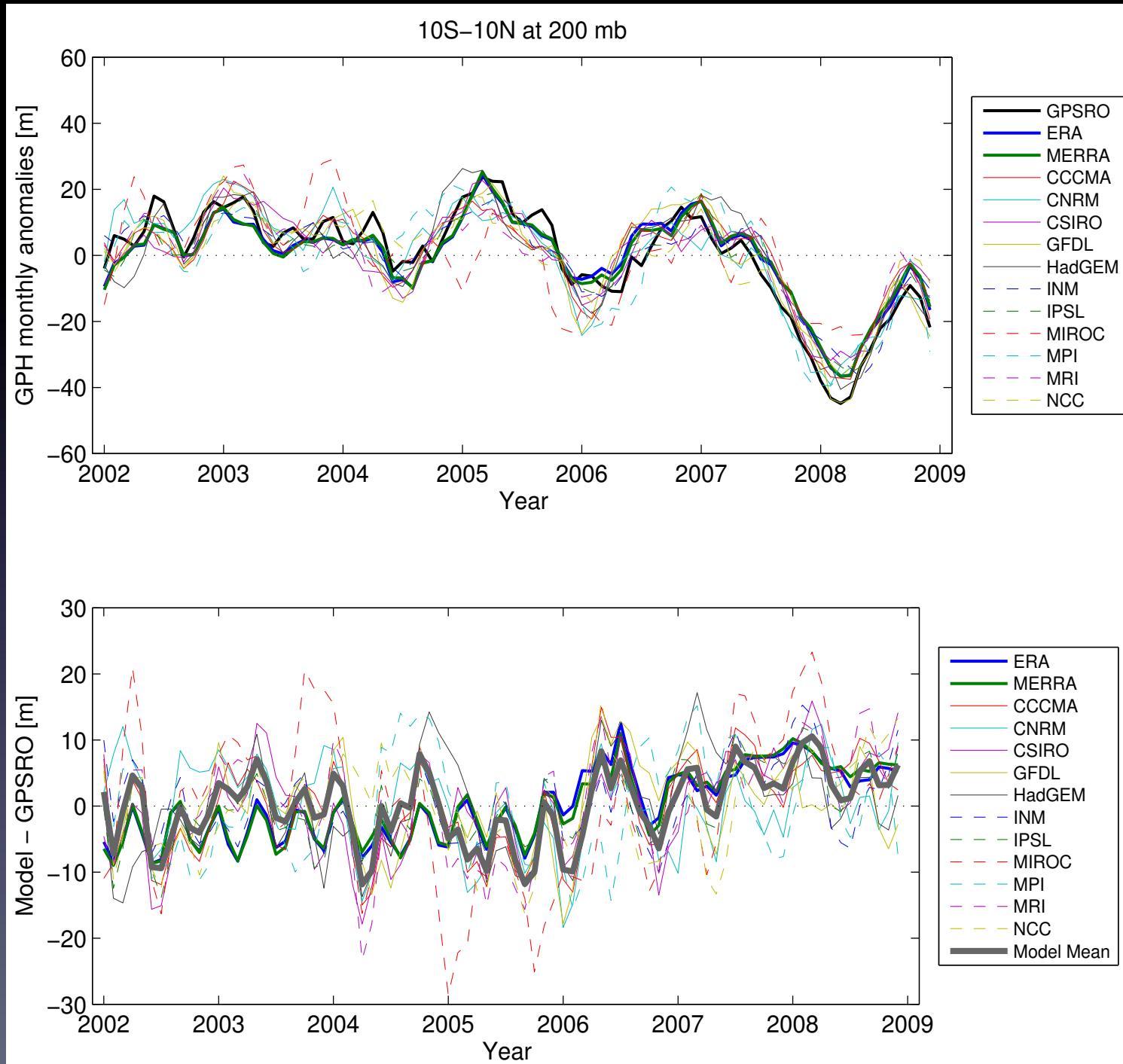
More  
different in  
N. High Lat

12

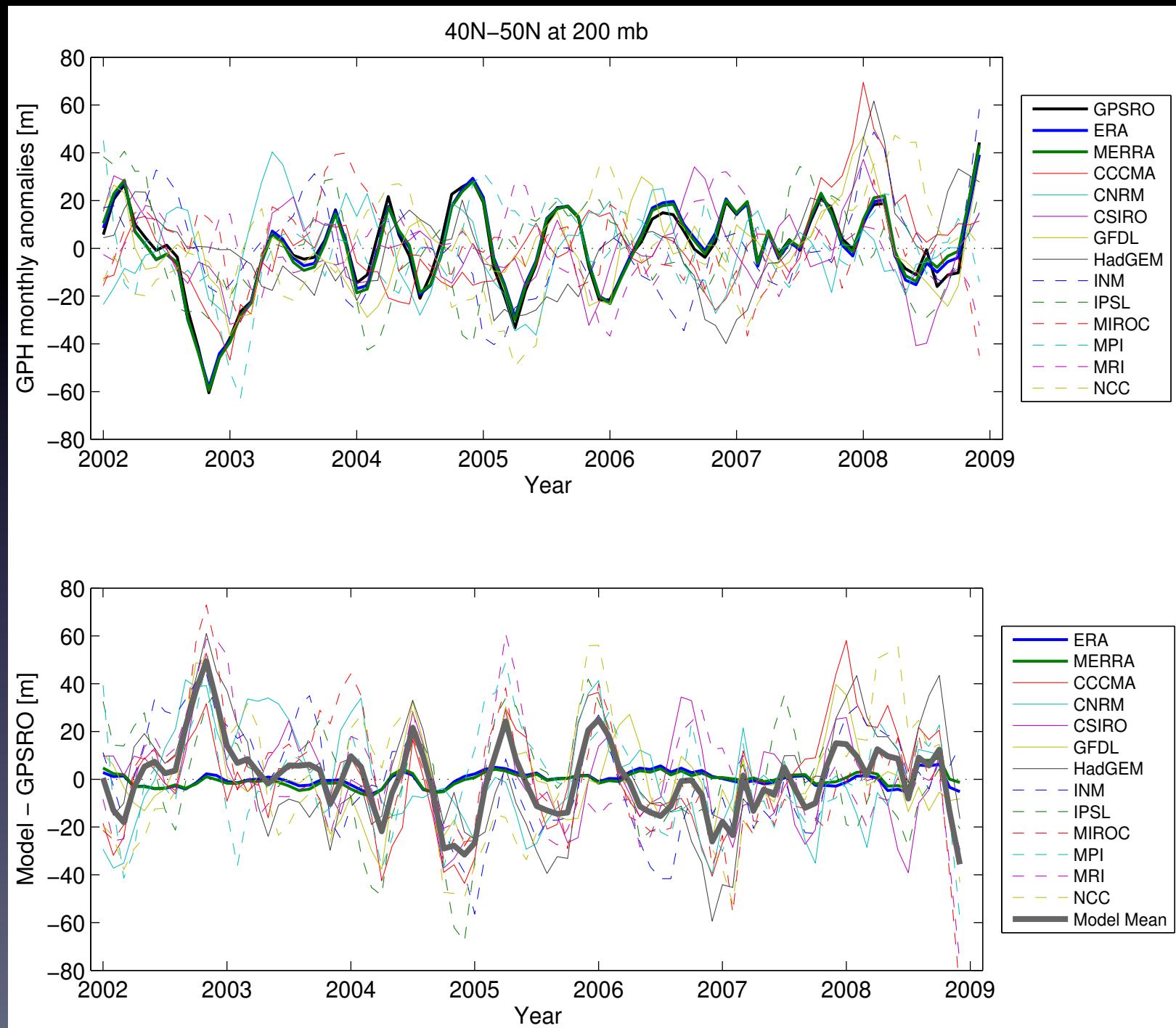
# Correlation of Monthly Anomalies (interannual variabilities)



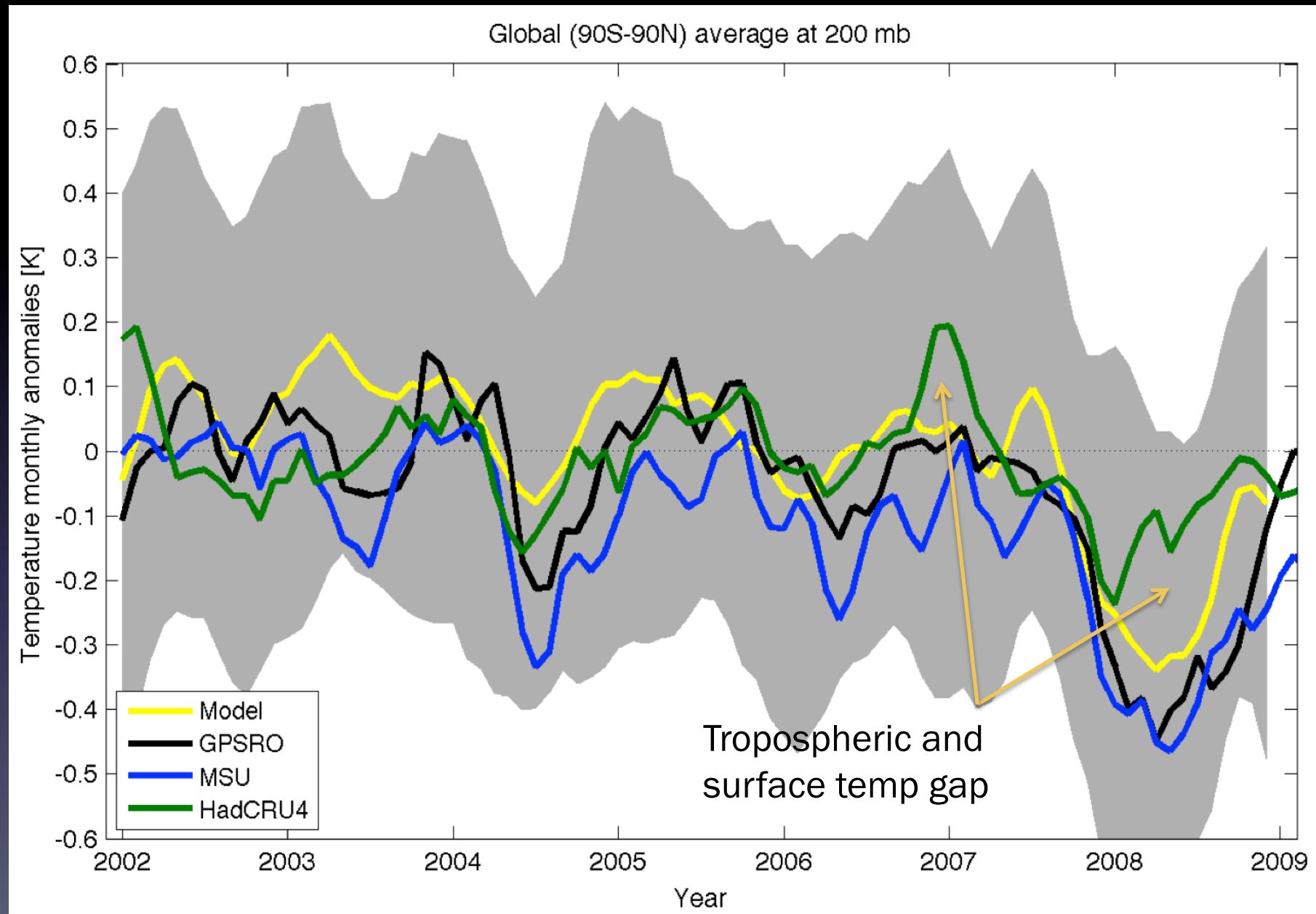
# Monthly Anomalies (Tropics)



# Monthly Anomalies (Mid-Lat)



# Tropospheric Temp. (Global)



# Conclusions (Part II)

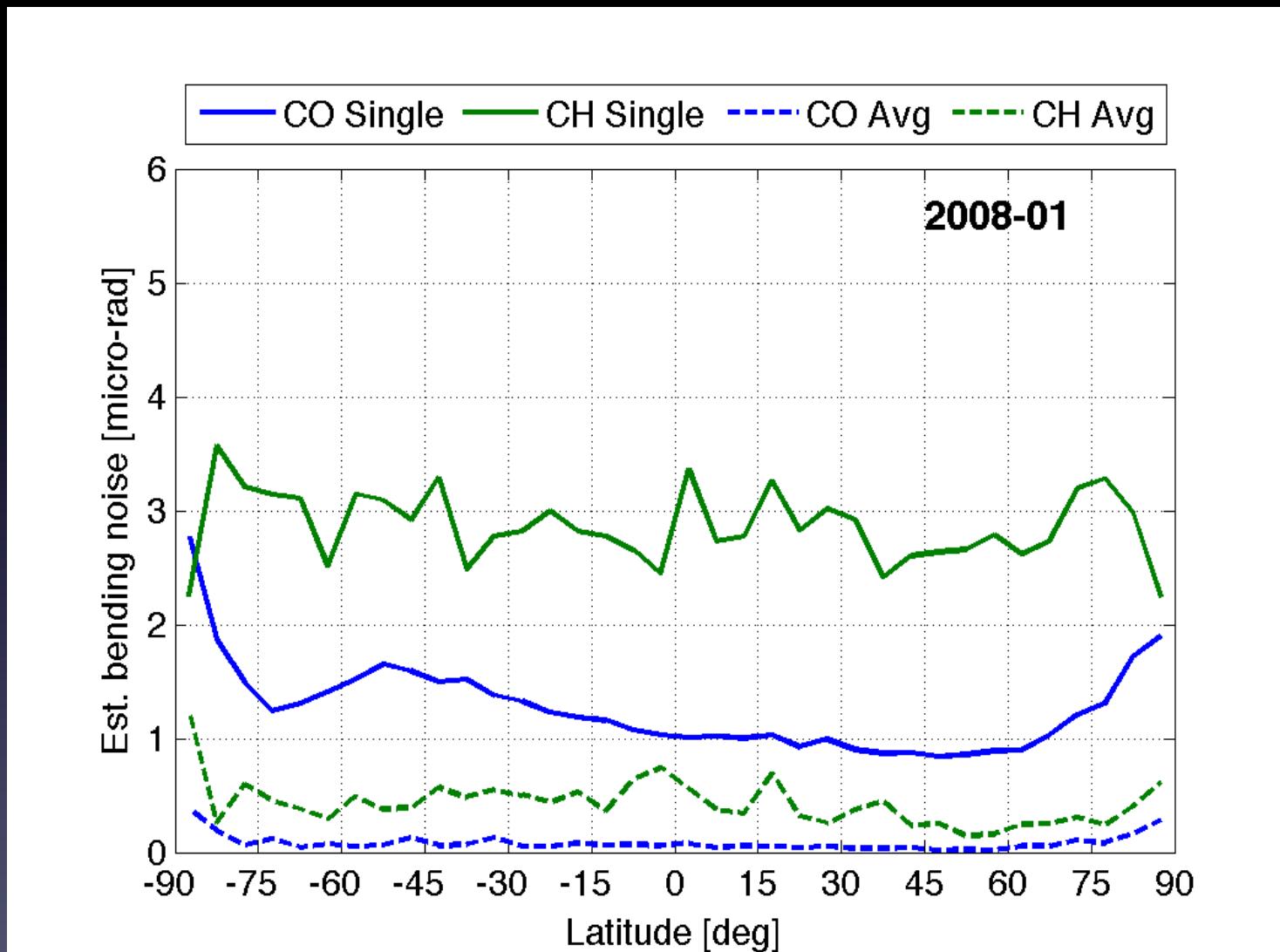
- GPH observations from GPS RO were compared with selected atmosphere-only model runs (AMIP) from the CMIP5 archive over 2002–2008.
- Most models matched well with the observations and reanalyses in the tropics in both the means and variabilities. However, the agreement was poor in the extratropics.
- Models have a consistently negative bias in the Southern high latitudes, while the inter-model spread is largest in the Northern high latitudes.
- Qualitatively similar results for 100 & 300 mb levels.

# III. Stratospheric Retrieval

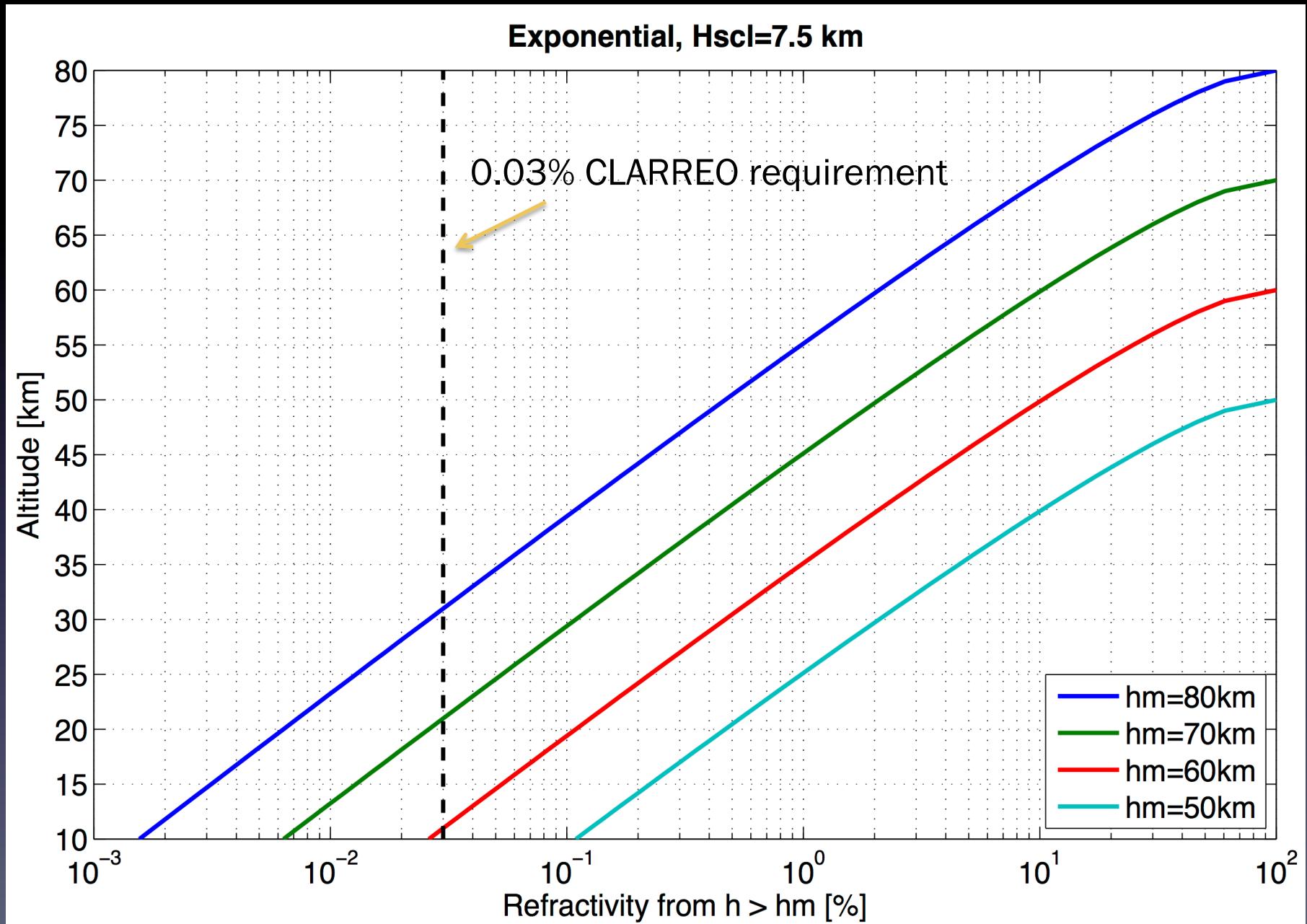
*C. O. Ao, A. J. Mannucci, and E. R. Kursinski, Improving GPS radio occultation stratospheric refractivity retrievals for climate benchmarking, GRL, 2012.*

- Further previous work, which improves stratospheric refractivity by extending the upper altitude of the bending angle obs by computing the average refractivity from the average bending angles (*average bending inversion* or ABI).
- Multi-center collaboration in characterizing the structural uncertainty of RO retrievals [Ho et al. 2012; Steiner et al. 2013]. JPL will lead new effort towards better understanding of differences in stratosphere.

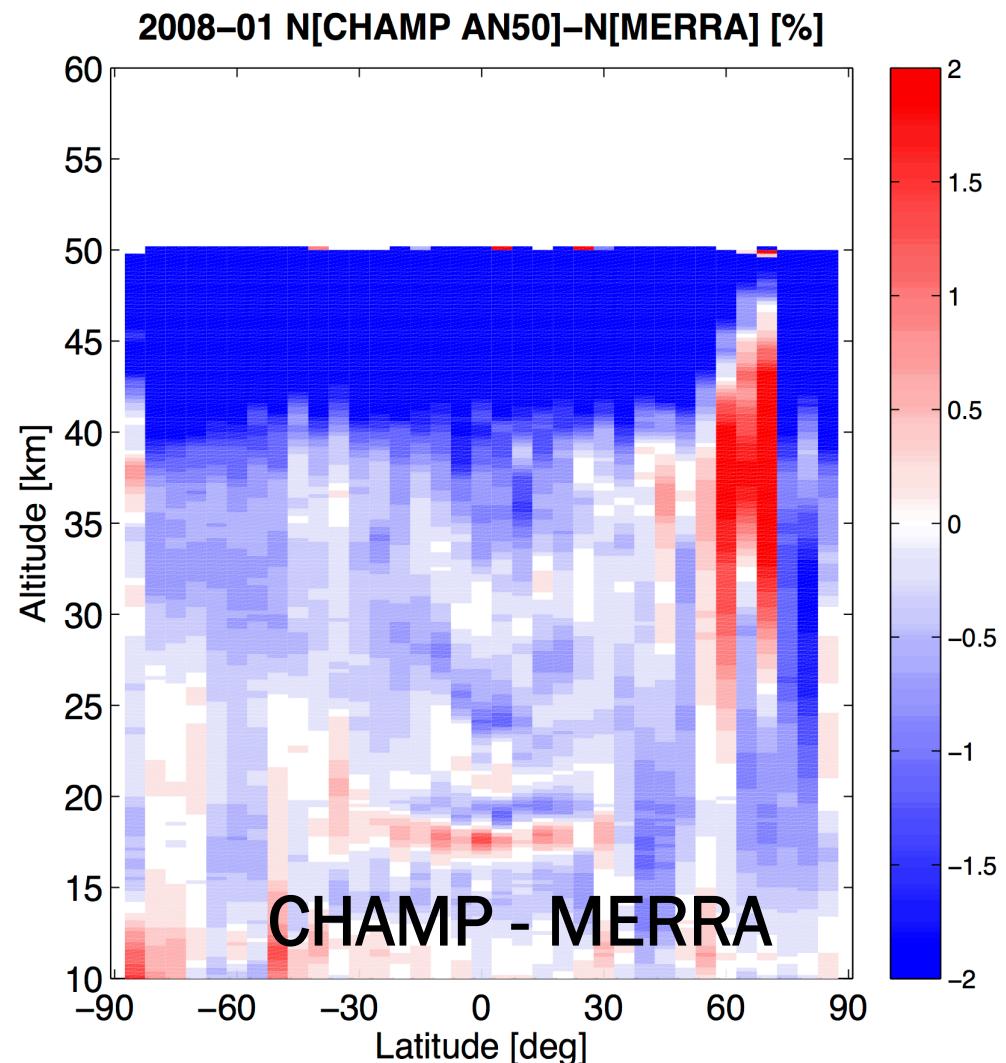
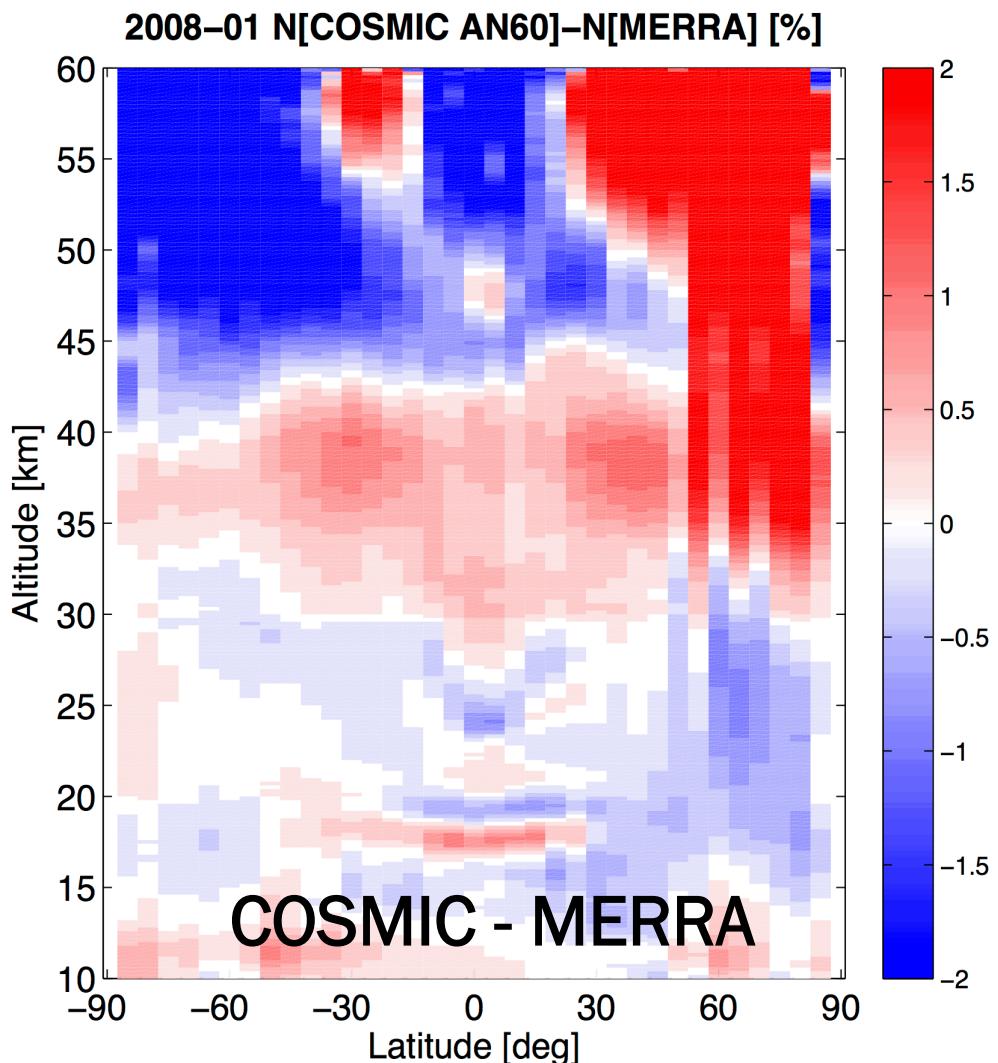
# Bending Angle Noise Reduction



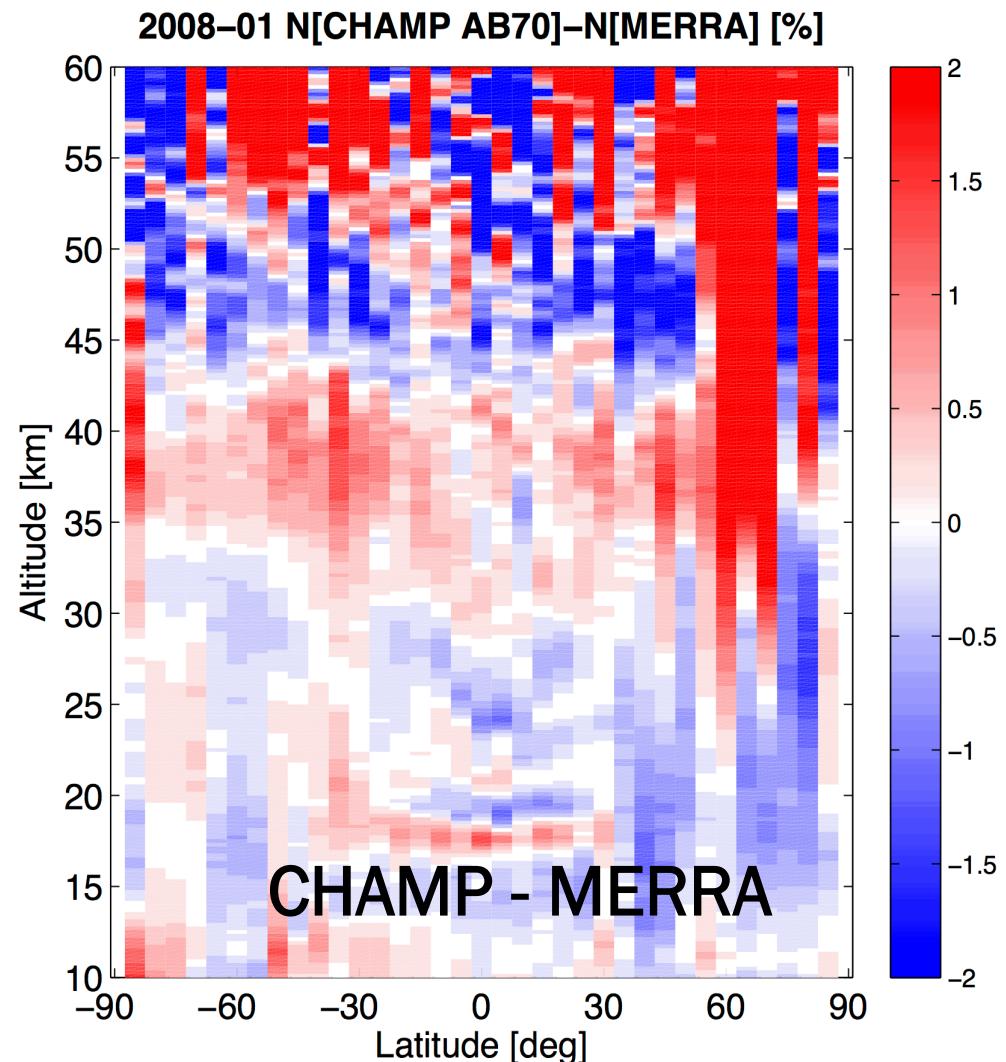
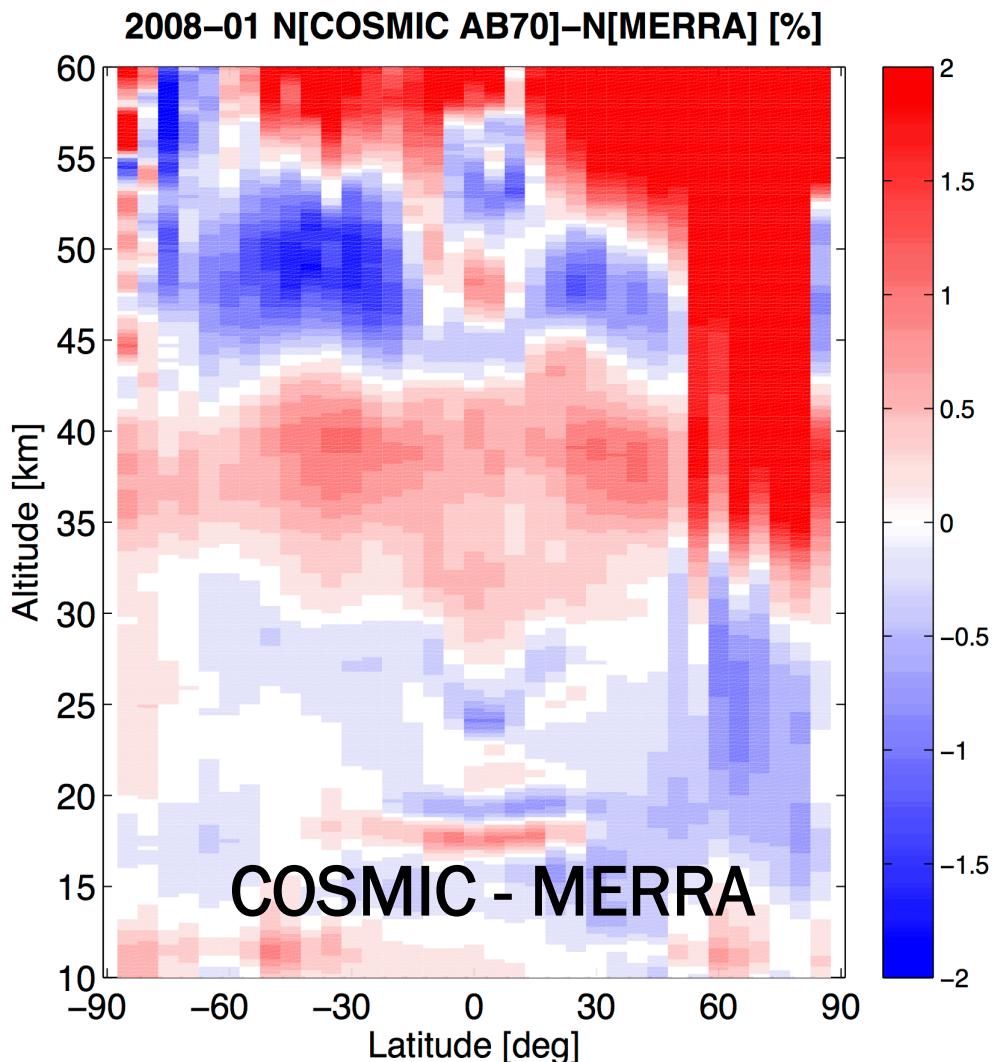
# Sensitivity to Top Height



# $\langle N \rangle$ from Individual Profiles



# $\langle N \rangle$ from $\langle BA \rangle$



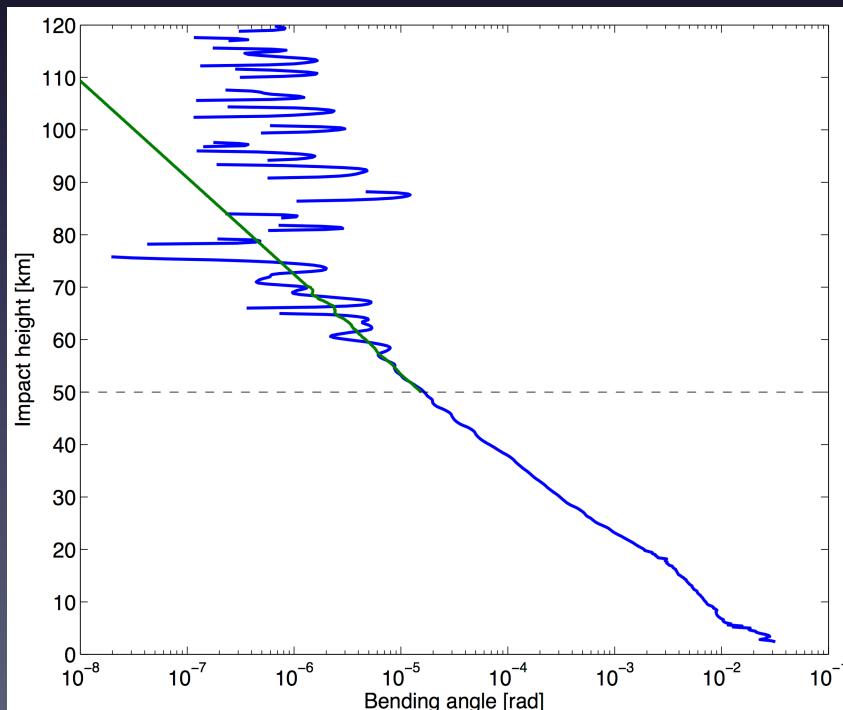
# Cons of ABI

- ABI approach has two down sides:
  - Nonlinearity leads to systematic  $\langle N \rangle$  errors in the troposphere.
  - Additional nonlinearity between T and N in the hydrostatic equation means that  $\langle T \rangle$  cannot be derived from  $\langle N \rangle$  directly.

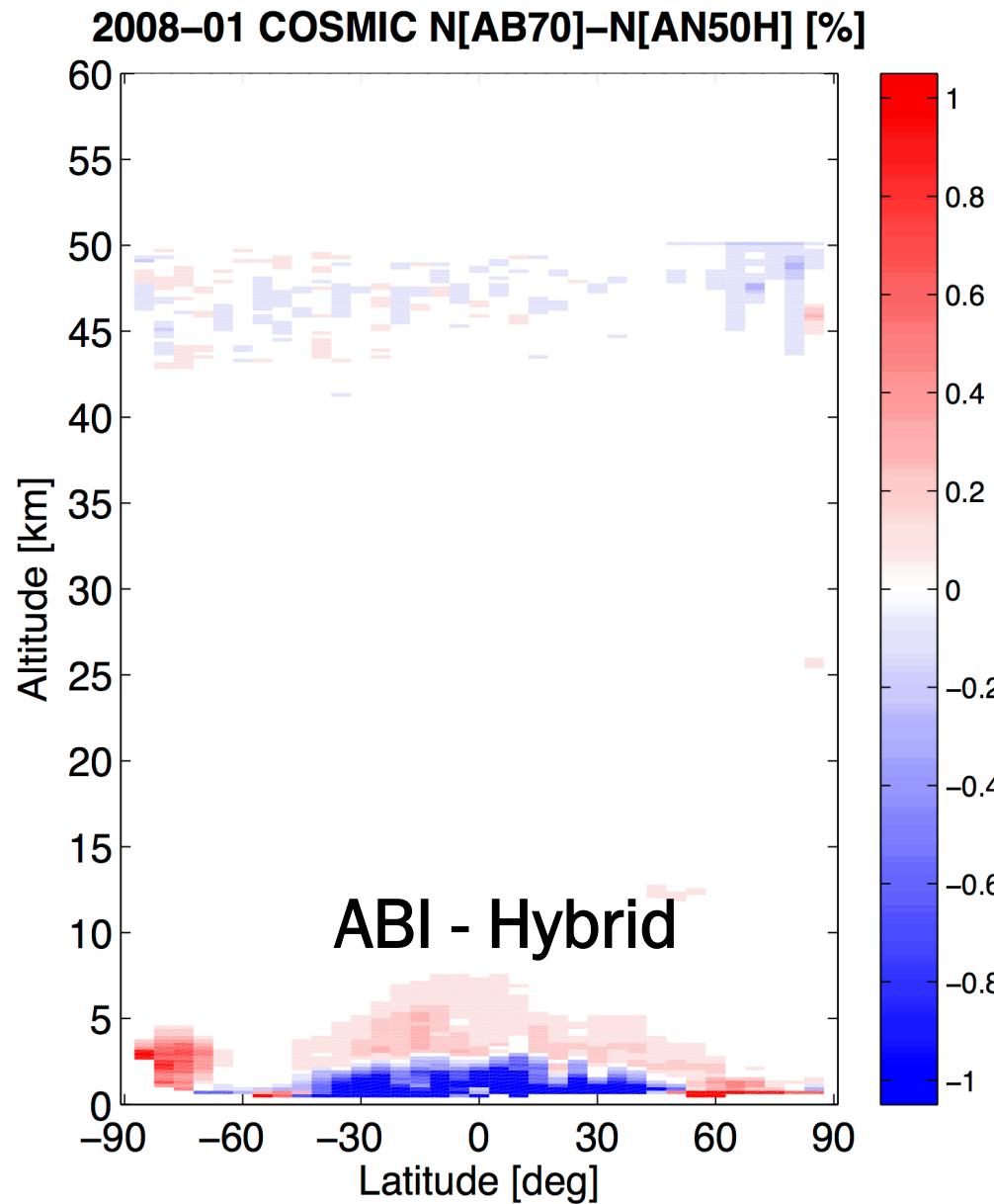
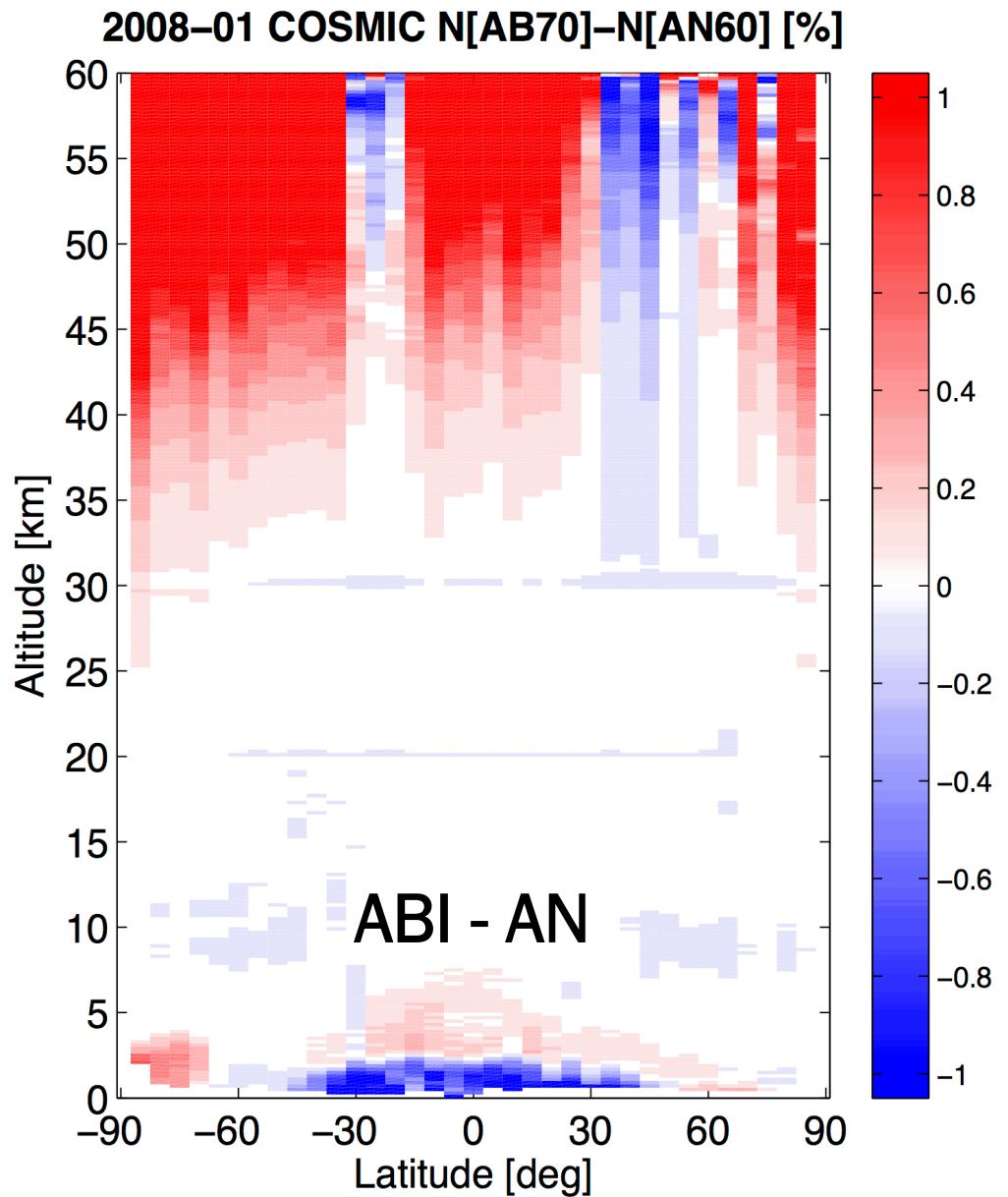
$$T(z) = T(z_m) \frac{N(z_m)}{N(z)} + \frac{m_d}{a_1 R} \int_z^{z_m} dz' g(z') \frac{N(z')}{N(z)}$$

# A Hybrid Approach

- Use  $\langle BA \rangle$  to extend individual BA profile above a certain height.
- Perform Abel inversion for each hybrid BA profile.
- Perform hydrostatic integration on each N profile.
- Average over individual N, T to obtain  $\langle N \rangle$ ,  $\langle T \rangle$ .



# $\langle N \rangle$ from Hybrid Approach



# Conclusions (Part III)

- ABI applied to CHAMP and COSMIC data showed clear improvement in the upper stratosphere, especially for the noisier CHAMP data.
- A hybrid approach that offers the advantage of ABI in the stratosphere and reduces the nonlinearity errors in the troposphere is promising.

# RO Missions Current & Pending

- COSMIC-1 (5 s/c) – IGOR
- GRACE-A – BlackJack
- TerraSAR-X – IGOR
- Tandem-X – IGOR
- Metop A/B – GRAS
- KOMPSAT- 5 – IGOR
- OceanSat-II – ROSA
- Aquarius/SAC-D – ROSA
- Megha-Tropiques – ROSA
- FY3-C – GNOS
- PAZ (2014) – IGOR
- COSMIC-2 Eq 6 s/c (2016) – TriG
- Metop C (2018)– GRAS
- COSMIC-2 Pol (?)
- GRACE Follow-on (?)
- JASON-CS (?)